Rocket History

Satellite and Space Systems MSc

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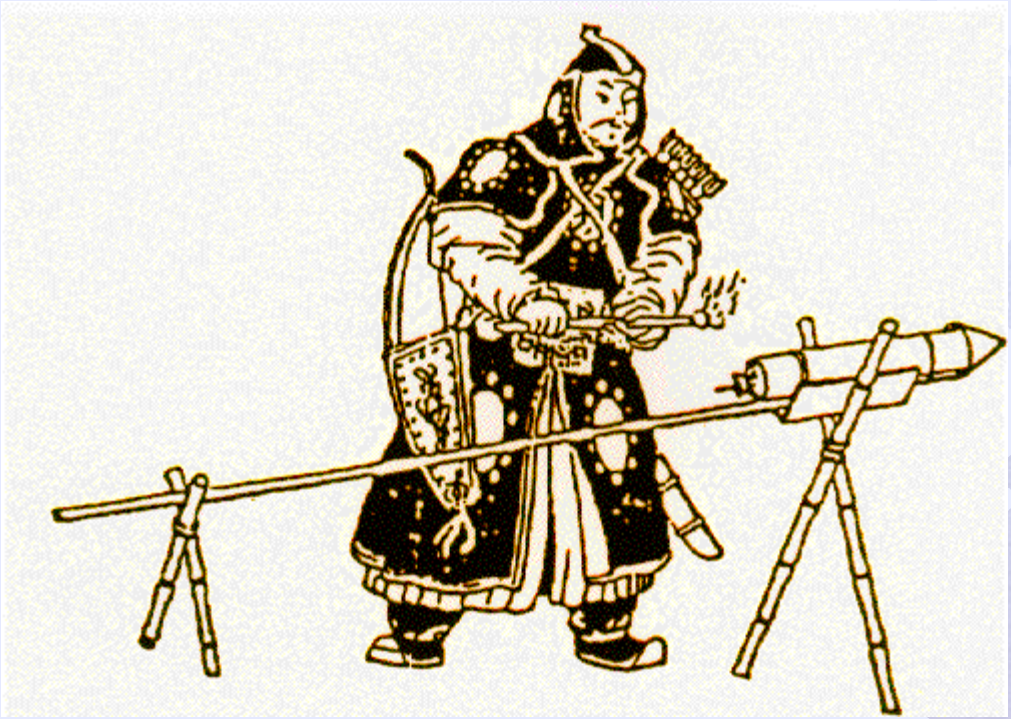
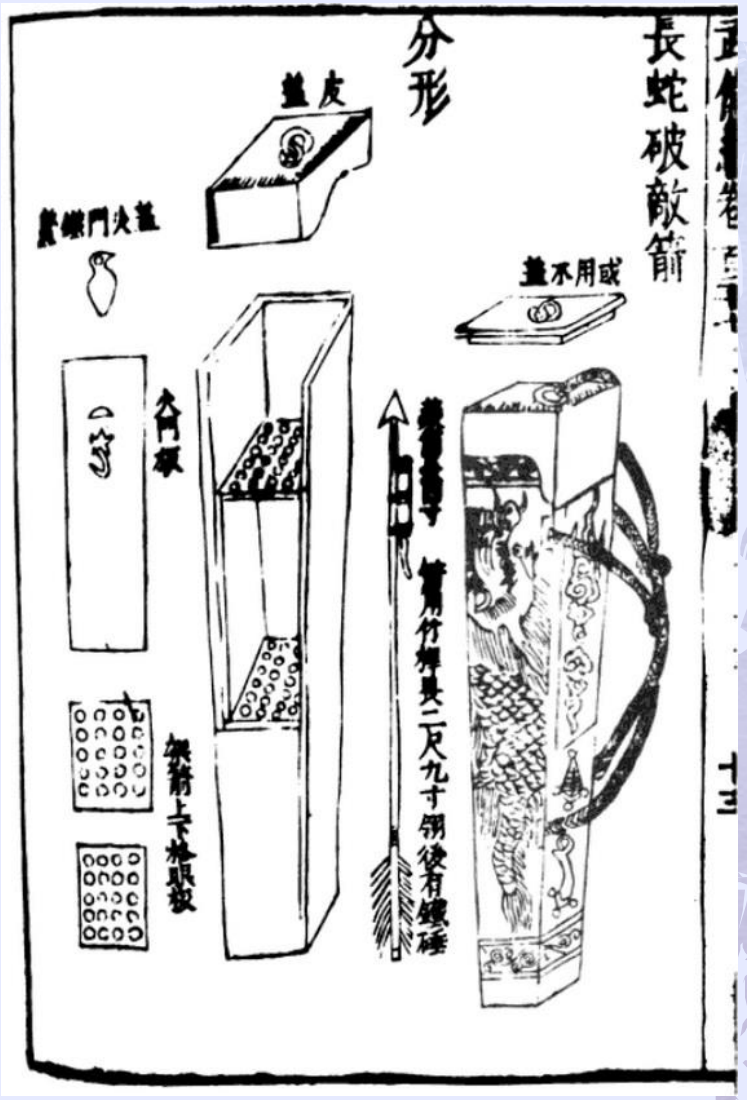
Who started rocketry

- A common claim is that the first recorded use of a rocket in battle was by the Chinese in 1232 against the Mongol hordes at Kai Feng Fu



Rocket Launcher

- A depiction of the "long serpent" rocket launcher from the 11th century book *Wujing Zongyao*.
- The holes in the frame are designed to keep the fire arrows separate



Konrad Kyeser (1405) depicts Alexander the Great Holding a Rocket

- Rocket technology was first known to Europeans following its use by the Mongols Genghis Khan and Ögedei Khan when they conquered parts of Russia, Eastern, and Central Europe.
- The Mongolians had acquired the Chinese technology by conquest of the northern part of China

Kazimierz Siemienowicz

- For over two centuries, the work of Polish-Lithuanian Commonwealth nobleman Kazimierz Siemienowicz "*Artis Magnae Artilleriae pars prima*" ("Great Art of Artillery, the First Part", also known as "The Complete Art of Artillery") - 1650, was used in Europe as a basic artillery manual.

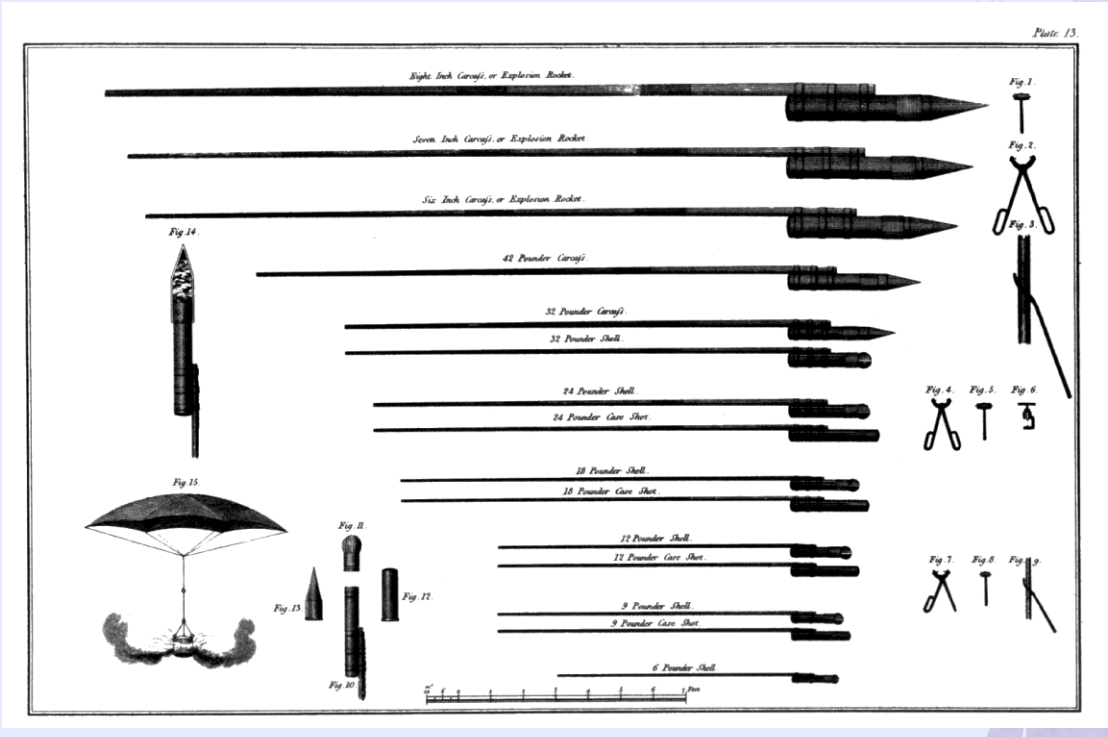
- It contained a large chapter on caliber, construction, production and properties of rockets (for both military and civil purposes), including
  - multi-stage rockets,
  - batteries of rockets, and
  - rockets with delta wing stabilizers (instead of the common guiding rods ("bottle rockets"),

Lagari Hasan Çelebi Rocket

- *Lagari Hasan Çelebi* was a legendary Ottoman aviator who, according to an account written by Evliya Çelebi, made a successful manned rocket flight.
- Evliya Çelebi purported that in 1633 Lagari Hasan Çelebi launched in a 7-winged rocket using 50 okka (140 lbs) of gunpowder from Saraybur nu, the point below Topkapı Palace in Istanbul.

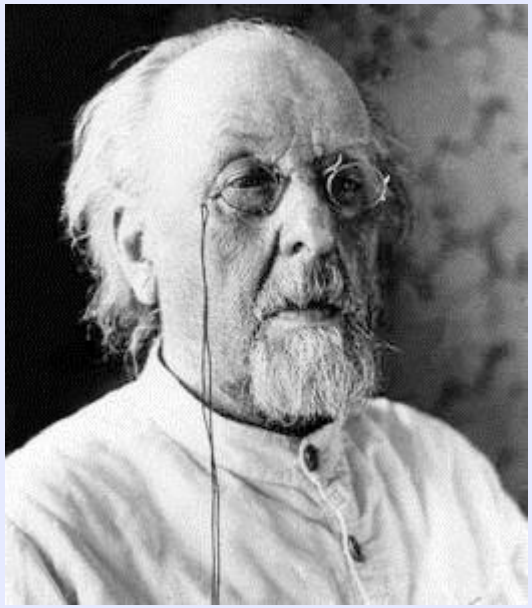
William Congreve

- Congreve prepared a new propellant mixture, and developed a rocket motor with a strong iron tube with conical nose.
- This early Congreve rocket weighed about 32 pounds (14.5 kilograms).
- The Royal Arsenal's first demonstration of solid fuel rockets was in 1805.
- The rockets were effectively used during the Napoleonic Wars and the War of 1812.



Konstantin Tsiolkovsky (1857–1935)

- The Tsiolkovsky rocket equation—the principle that governs rocket propulsion—is named in his honor (although it had been discovered previously).
- He also advocated the use of liquid hydrogen and oxygen for propellant, calculating their maximum exhaust velocity.
- His work was essentially unknown outside the Soviet Union
- *Book: The Exploration of Cosmic Space by Means of Reaction Devices*



$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

Where $v_e =$ *exit velocity is fixed by the choice of fuel*; $m_0 =$ *initial mass*; $m_1 =$ *final mass at burn out*;

Robert Goddard

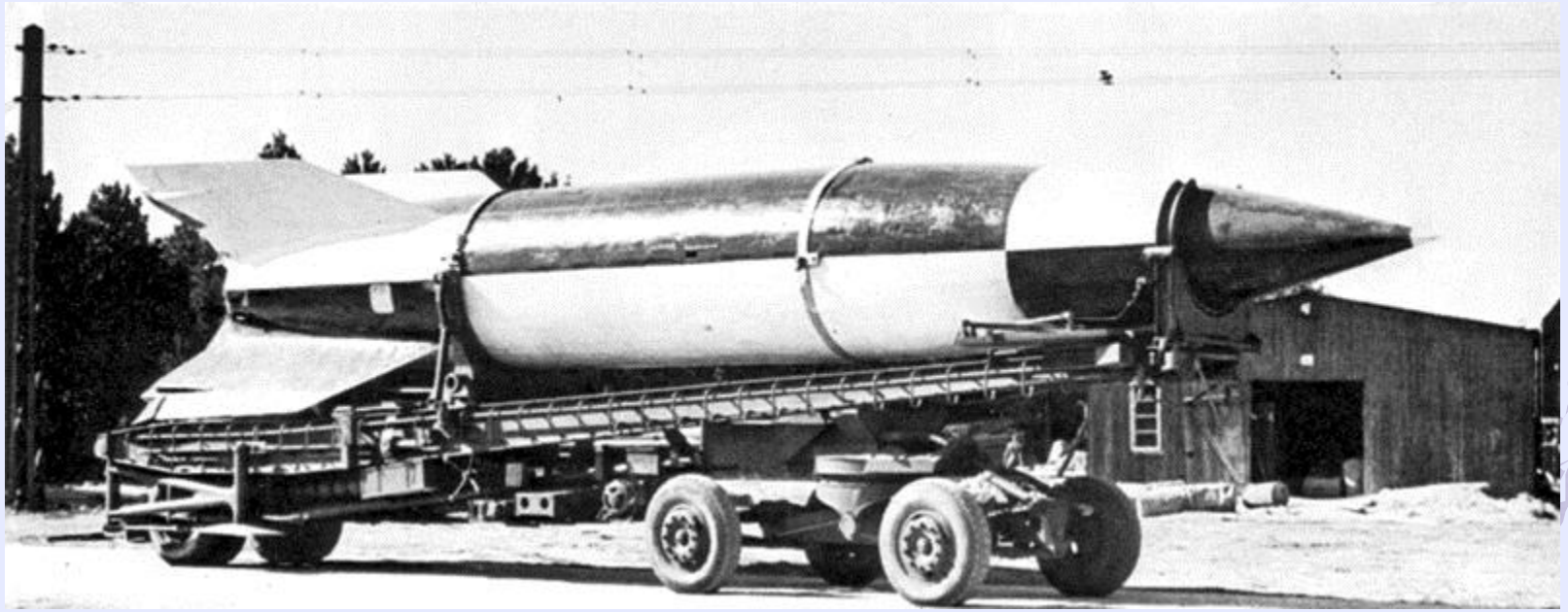
- In 1912 Robert Goddard, inspired from an early age by H.G. Wells, began a serious analysis of rockets, concluding that conventional solid-fuel rockets needed to be improved in three ways.
- First, fuel should be burned in a small combustion chamber, instead of building the entire propellant container to withstand the high pressures.
- Second, rockets could be arranged in stages.
- Finally, the exhaust speed (and thus the efficiency) could be greatly increased to beyond the speed of sound by using a De Laval nozzle.

Robert Goddard

- Robert Goddard and the first liquid-fuelled rocket
- The de Laval nozzle was developed by Swedish inventor Gustaf de Laval in 1888 for use on a steam turbine

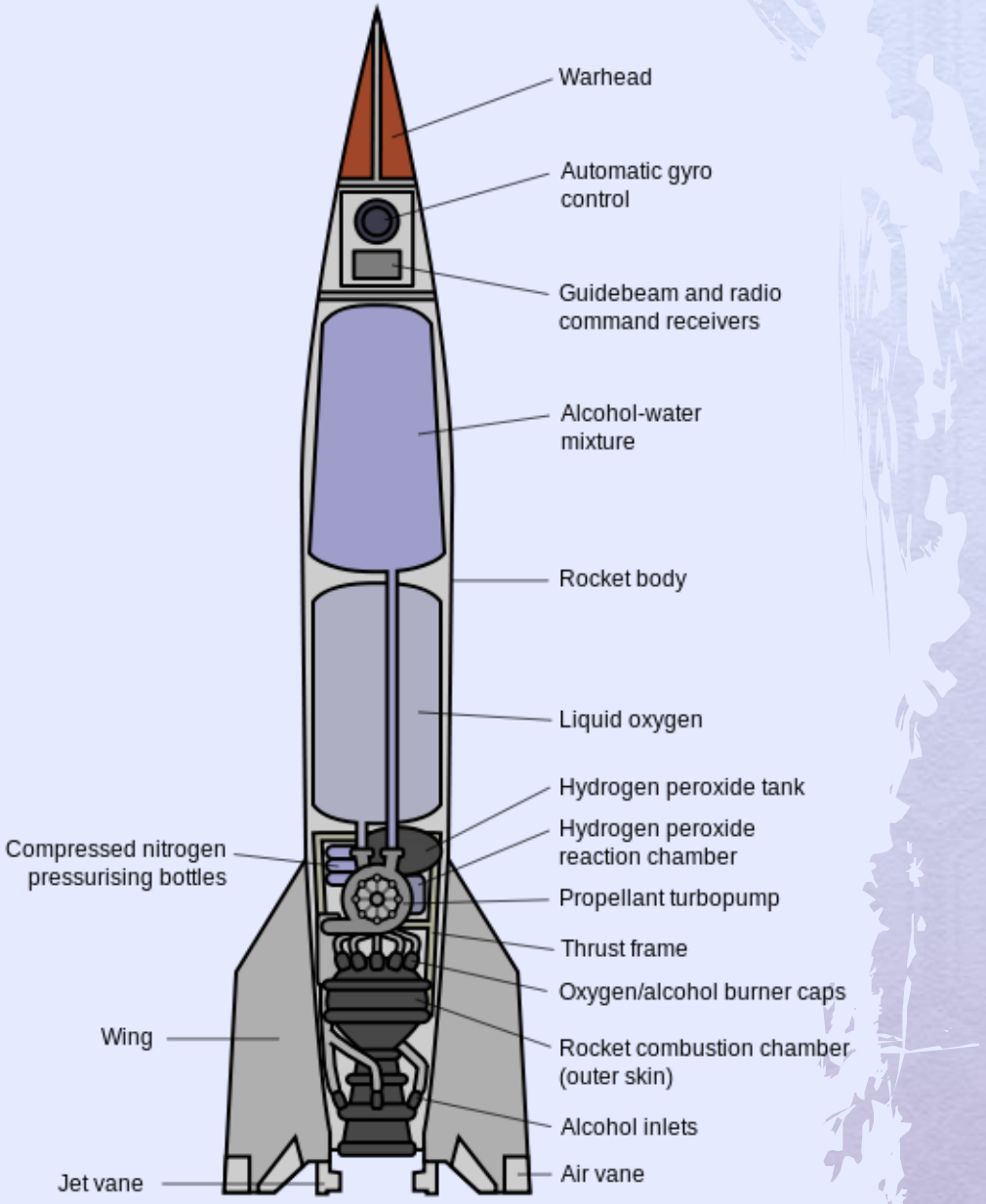
V2 Rocket

- In 1943, production of the V-2 rocket began in Germany. It had an operational range of 300 km (190 mi) and carried a 1,000 kg (2,200 lb) warhead, with an amatol explosive charge.
- It normally achieved an operational maximum altitude of around 90 km (56 mi), but could achieve 206 km (128 mi) if launched vertically
- **Amatol** is a highly explosive material made from a mixture of TNT and ammonium nitrate.



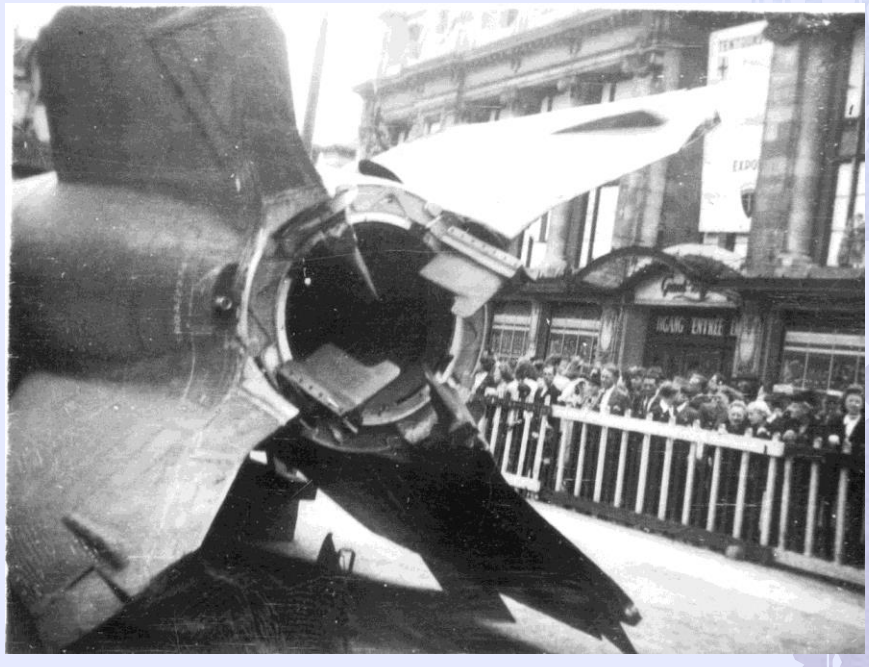
Milestone V2

- Layout of the V2 Rocket
- The vehicle was similar to most modern rockets, with turbopump, inertial guidance and many other features.



Control System

- The V-2 was guided by four external rudders on the tail fins, and four internal graphite vanes at the exit of the motor.
- The LEV-3 guidance system consisted of two free gyroscopes (a horizontal and a vertical) for lateral stabilization, and
- a PIGA (*Pendulous Integrating Gyroscopic Accelerometer*) accelerometer to control engine cut-off at a specified velocity.



Dornberger and Von Braun after being captured by the Allies

- At the end of World War II, competing Russian, British, and US military and scientific crews raced to capture technology and trained personnel from the German rocket program at Peenemünde
- The V-2 evolved into the American Redstone rocket, used in the early space program

They Worked

- Aftermath of a V-2 bombing at Hughes Mansions, Vallance Road, Whitechapel, London, 27 March 1945

R-7 8K72 "Vostok" permanently displayed at the Moscow Trade Fair

- Independently, in the Soviet Union's space program research continued under the leadership of the chief designer Sergei Korolev
- With the help of German technicians, the V-2 was duplicated and improved as the R-1, R-2 and R-5 missiles.
- German designs were abandoned in the late 1940s, and the foreign workers were sent home
- A new series of engines built by Glushko and based on inventions of Aleksei Mihailovich Isaev formed the basis of the first ICBM, the R-7
- The R-7 launched the first satellite-Sputnik 1, 1958 and later Yuri Gagarin-the first man into space

Von Braun's rocket team in 1961

- In America the manned programmes, Project Mercury, Project Gemini and later the Apollo programme culminated in 1969 with the first manned landing on the moon via the Saturn V,
- The New York Times had to retract their earlier editorial implying that spaceflight couldn't work

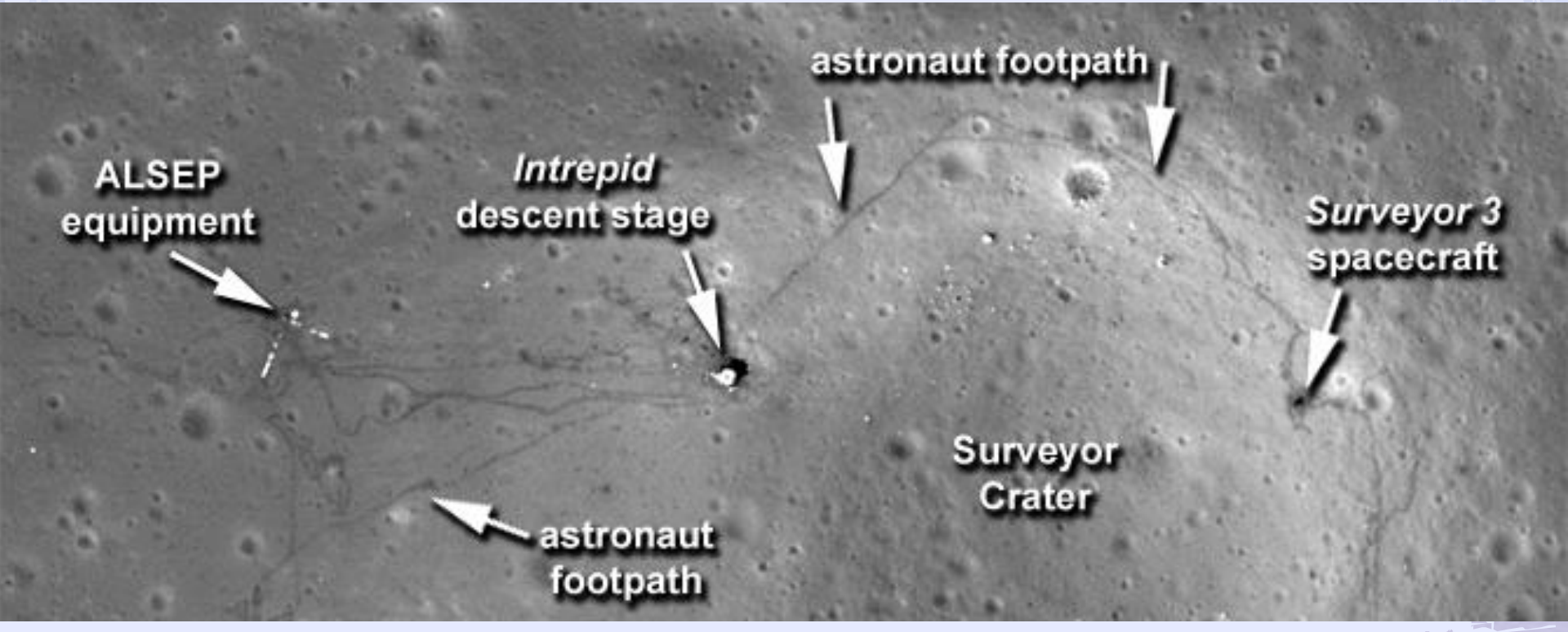
Space Ship One

- SpaceShipOne for suborbital tourism may show a trend towards greater commercialisation of manned rocketry

Saturn V

- Saturn V is the biggest rocket to have successfully flown.
- The **Saturn V** was an American human-rated expendable rocket used by NASA between 1966 and 1973.
- The three-stage, liquid-fueled launch vehicle was developed to support the Apollo program for human exploration of the Moon, and was later used to launch Skylab
- Mass: 2,970,000 kg; height: 110.6m, dia: 10.1m

LRO images of the Apollo 12 landing site 6th September 2011

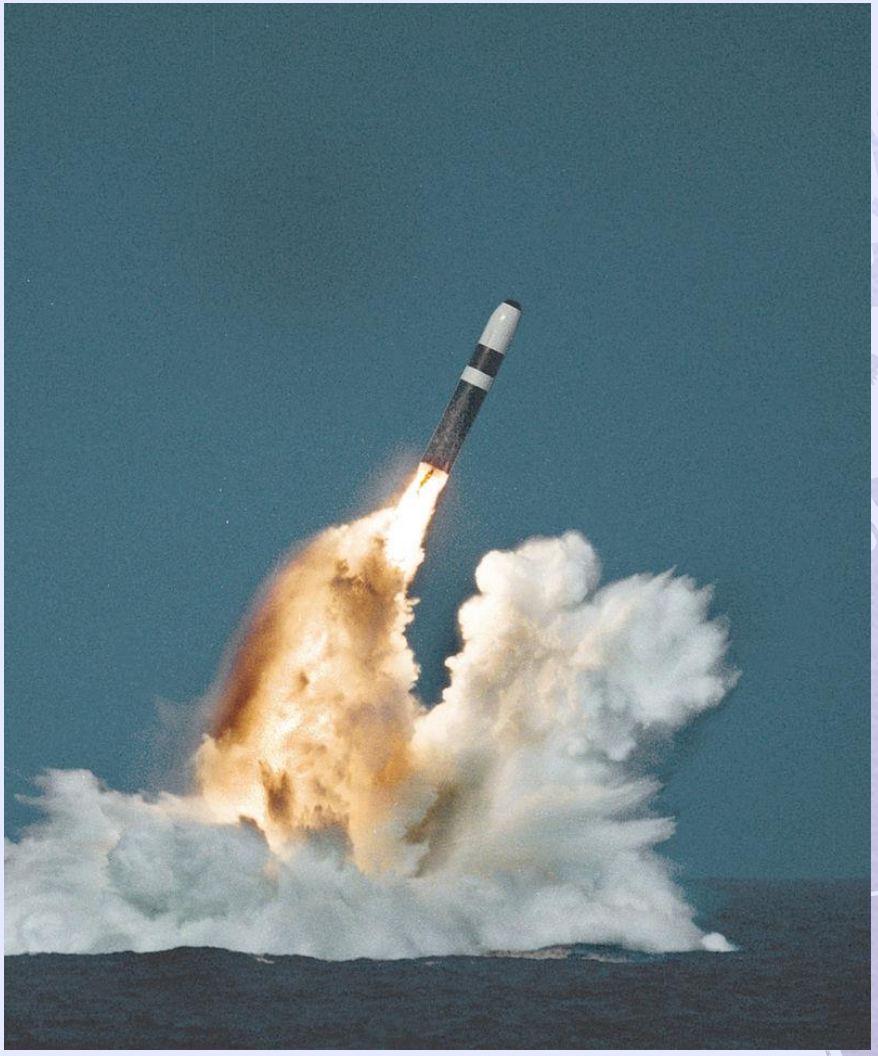


Viking 5C rocket engine

- The Viking 5C Rocket Engine. The engine was designed and manufactured by six countries: France, Germany, Spain, Belgium, Sweden and Italy. It was used in first stage of Ariane 4 from 1990 to 2003.

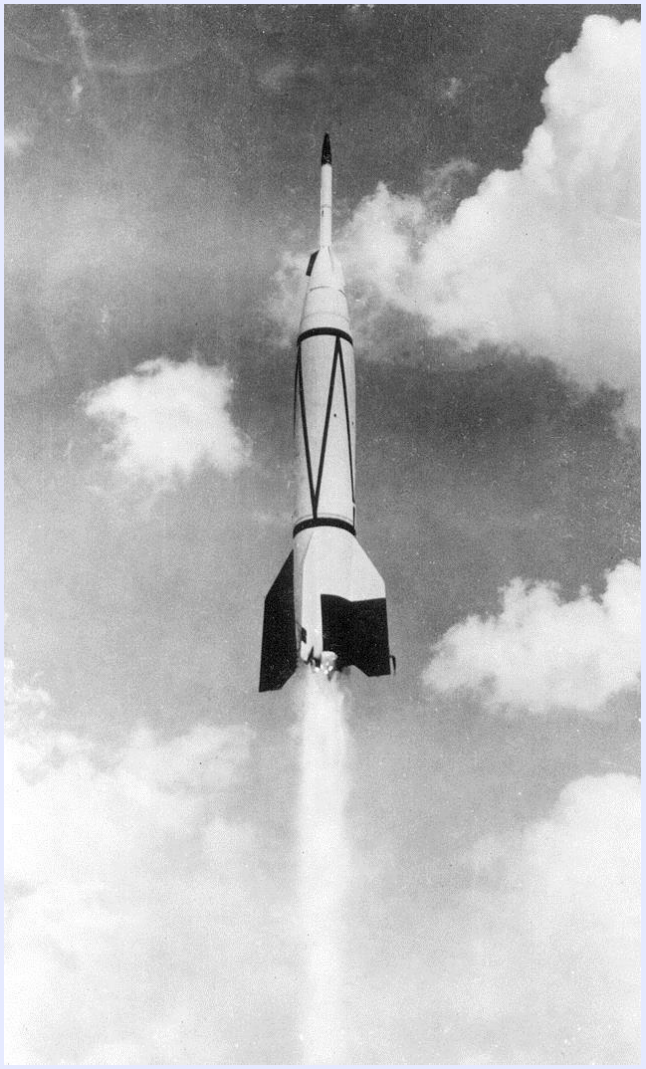
Trident II

- A Trident II missile launched from a Royal Navy *Vanguard* class ballistic missile submarine.

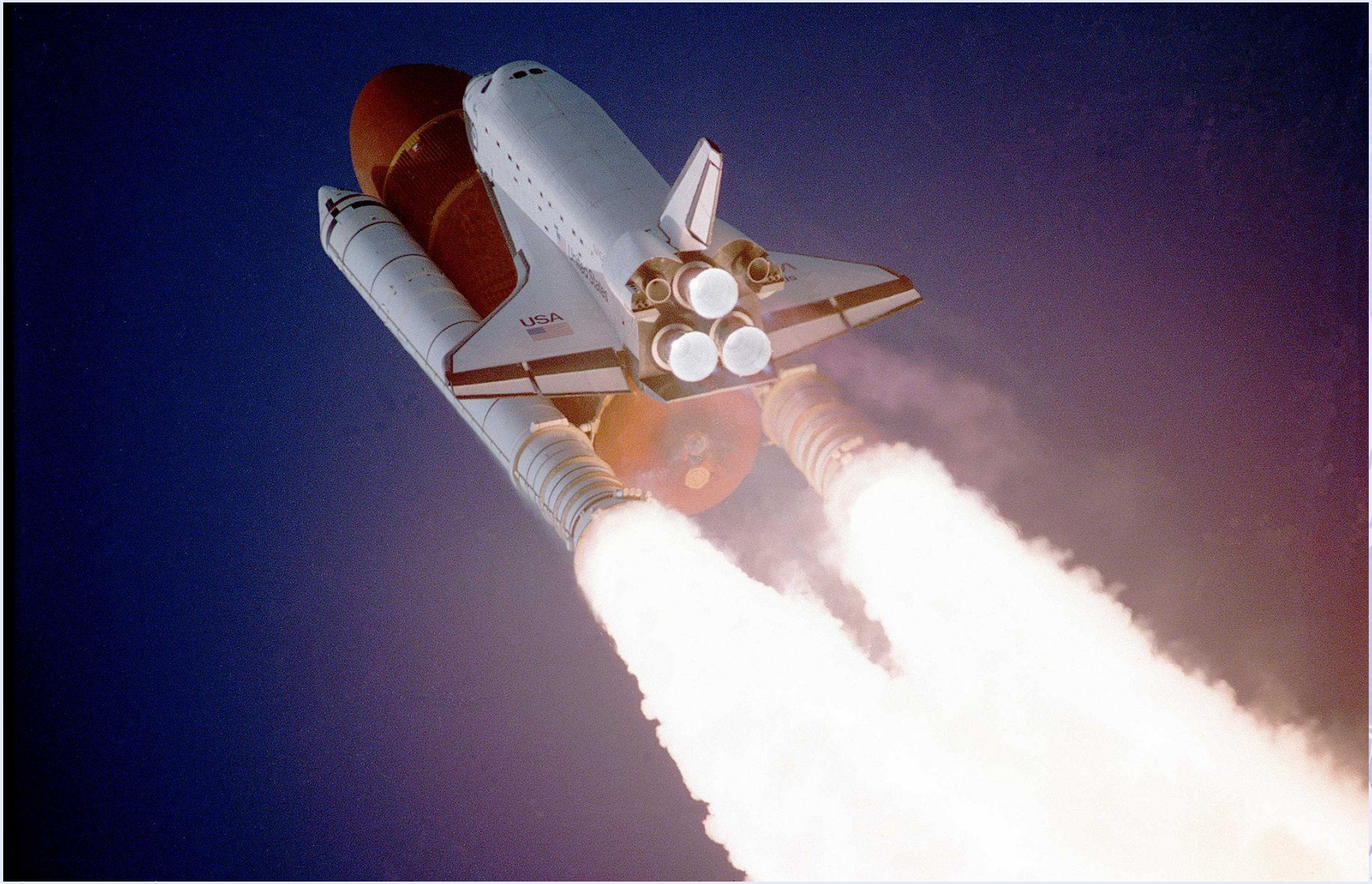


A Bumper sounding rocket

- Sounding rockets are commonly used to carry instruments that take readings from 50 kilometers (31 mi) to 1,500 kilometers (930 mi) above the surface of the Earth.
- The altitudes between those reachable by weather balloons and satellites

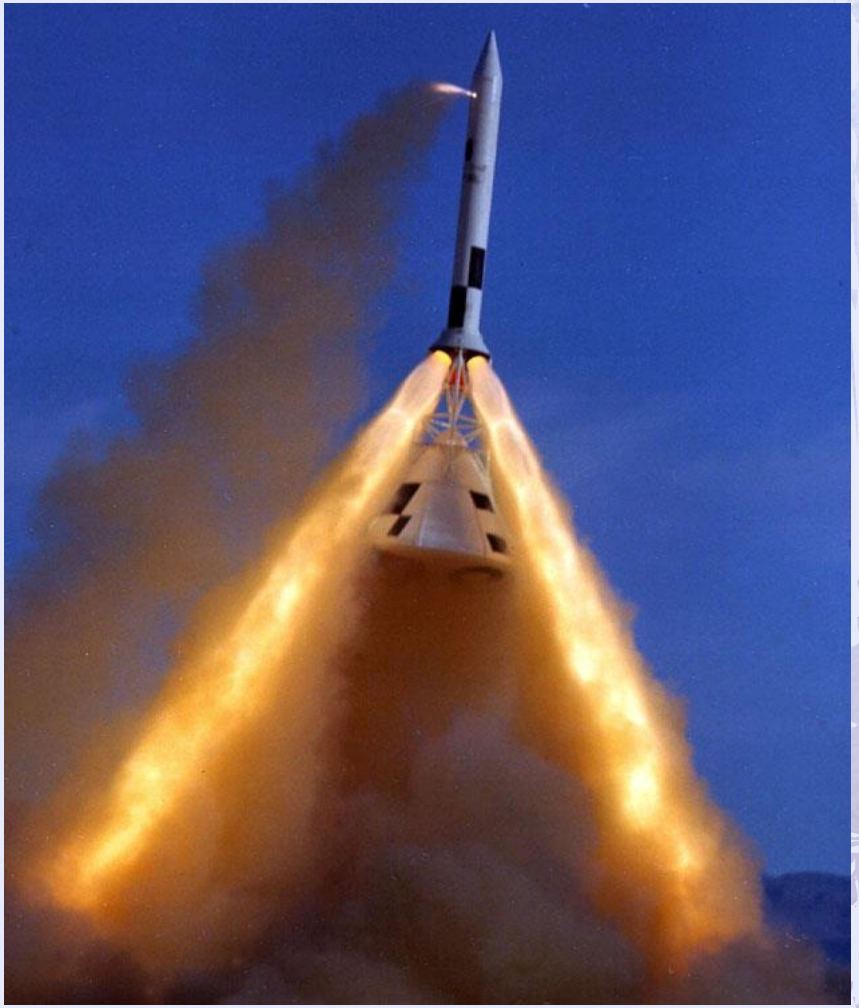


Space Shuttle *Atlantis* during launch phase



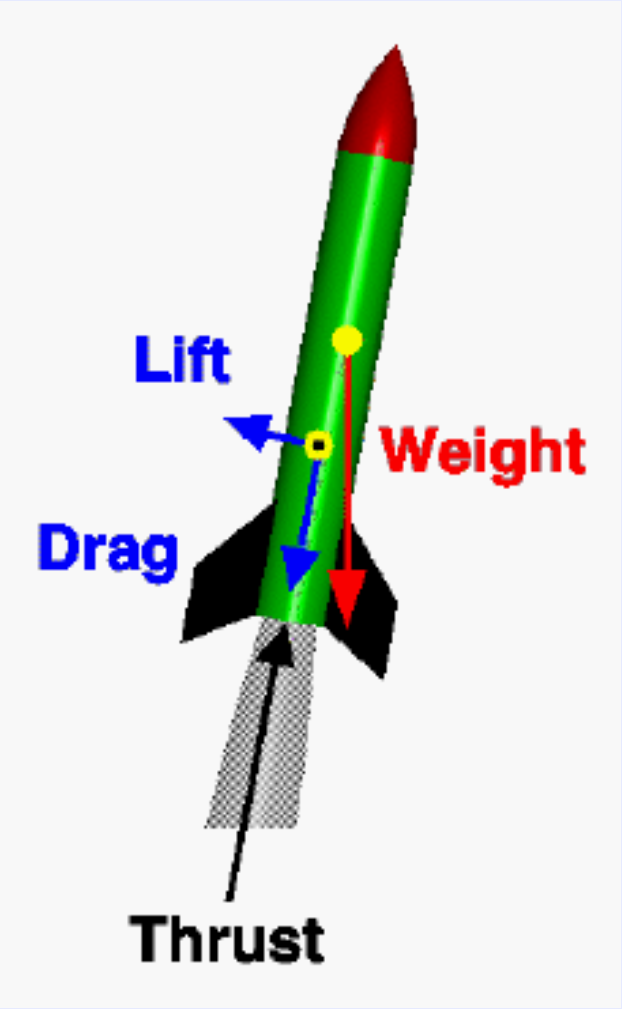
Apollo LES pad abort test

- Some crewed rockets, notably the Saturn V and Soyuz have launch escape systems.
- This is a small, usually solid fuel rocket that is capable of pulling the crewed capsule away from the main vehicle towards safety at a moments notice.



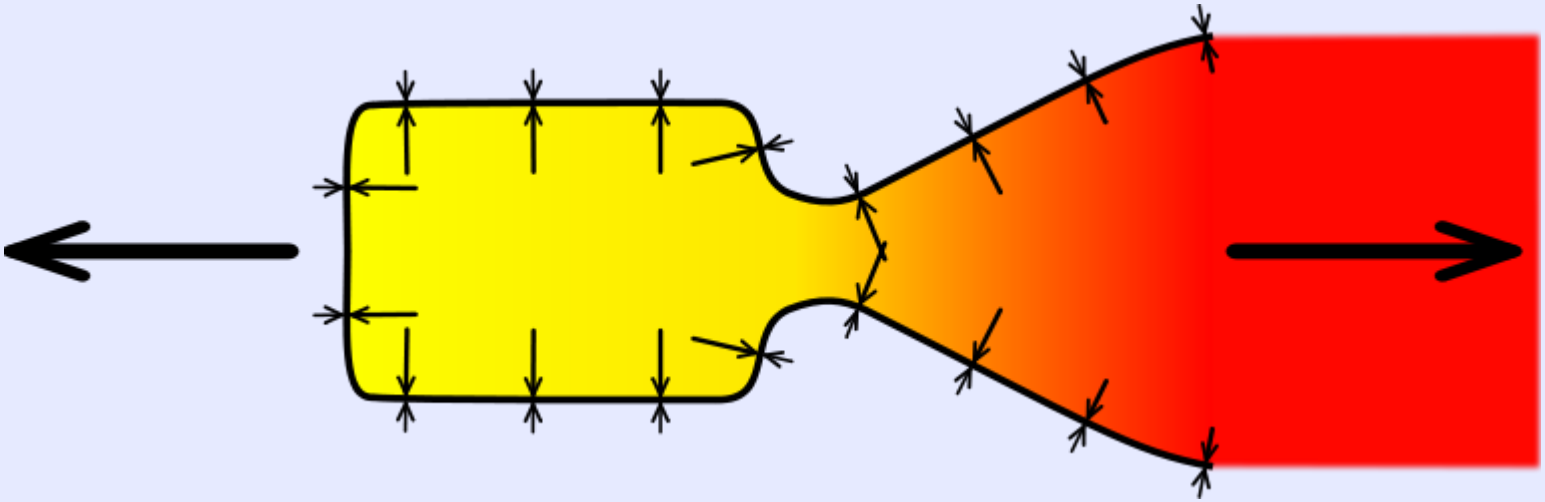
Forces on a Rocket

- Forces on a rocket in flight, rockets that must travel through the air are usually tall and thin as this shape gives a high ballistic coefficient and minimizes drag losses



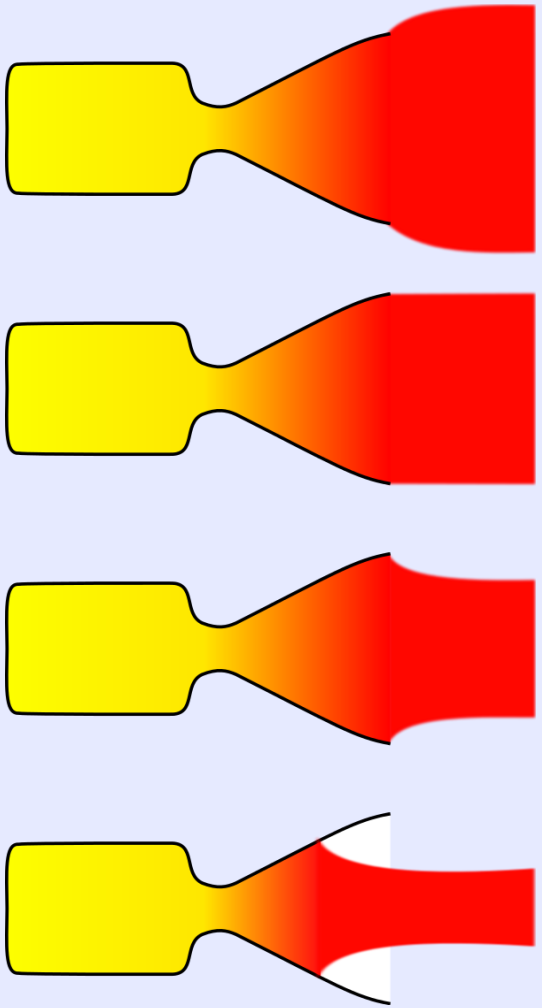
Convergent/Divergent nozzle

- Using a convergent/divergent nozzle gives more force since the exhaust also presses on it as it expands outwards, roughly doubling the total force.
- Note that the pumps moving the propellant into the combustion chamber must maintain a pressure larger than the combustion chamber -typically of the order of 100 atmospheres.



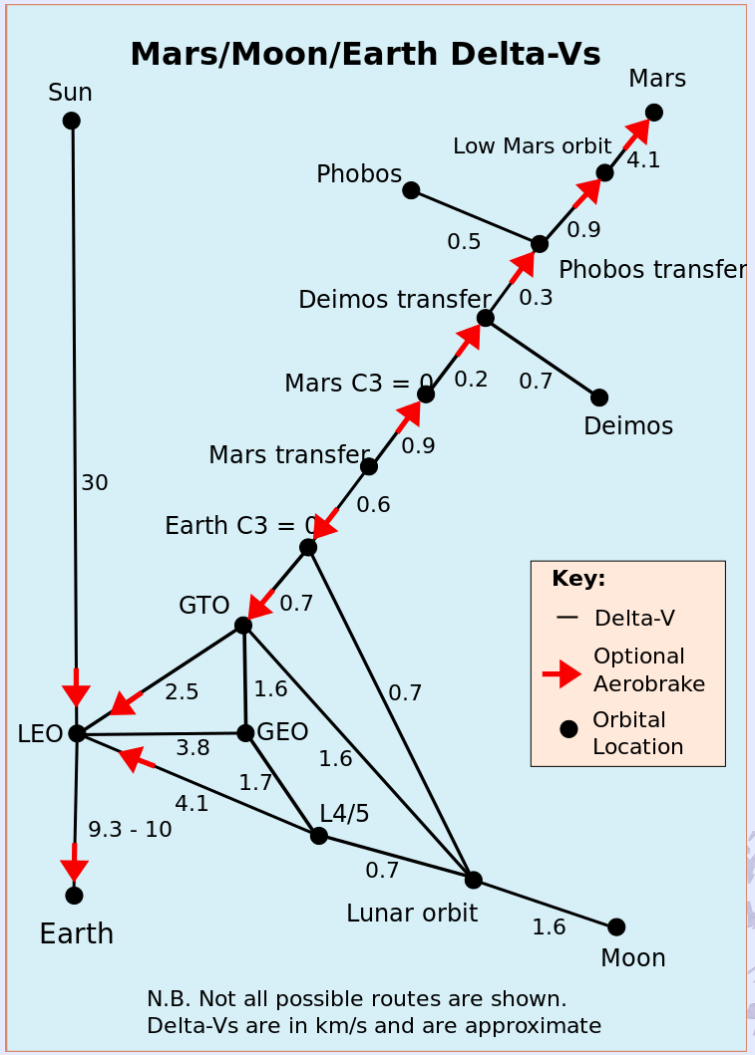
Convergent/Divergent nozzle

- Due to the supersonic nature of the exhaust jet the exit pressure can be different from the ambient atmospheric pressure.
- *Nozzles* are said to be (top to bottom):
  - **Underexpanded** (above ambient).
  - **Ambient**.
  - **Overexpanded** (below ambient).
  - **Grossly overexpanded**.
- If under or overexpanded then loss of efficiency occurs, grossly overexpanded nozzles lose less efficiency, but the exhaust jet is usually unstable.
- Rockets become progressively more underexpanded as they gain altitude.
- Note that almost all rocket engines are momentarily grossly overexpanded during startup in an atmosphere.



Delta-v's from the Rocket Equation

- A map of approximate Delta-v's around the solar system between Earth and Mars
- The required delta-v can also be calculated for a particular manoeuvre; for example the delta-v to launch from the surface of the Earth to Low earth orbit is about 9.7 km/s



Mass Ratio

- The Tsiolkovsky rocket equation gives a relationship between the mass ratio and the final velocity in multiples of the exhaust speed
- Almost all of a launch vehicle's mass consists of propellant.
- Mass ratio is, for any 'burn', the ratio between the rocket's initial mass and the mass after burnout.
- Everything else being equal, a high mass ratio is desirable for good performance

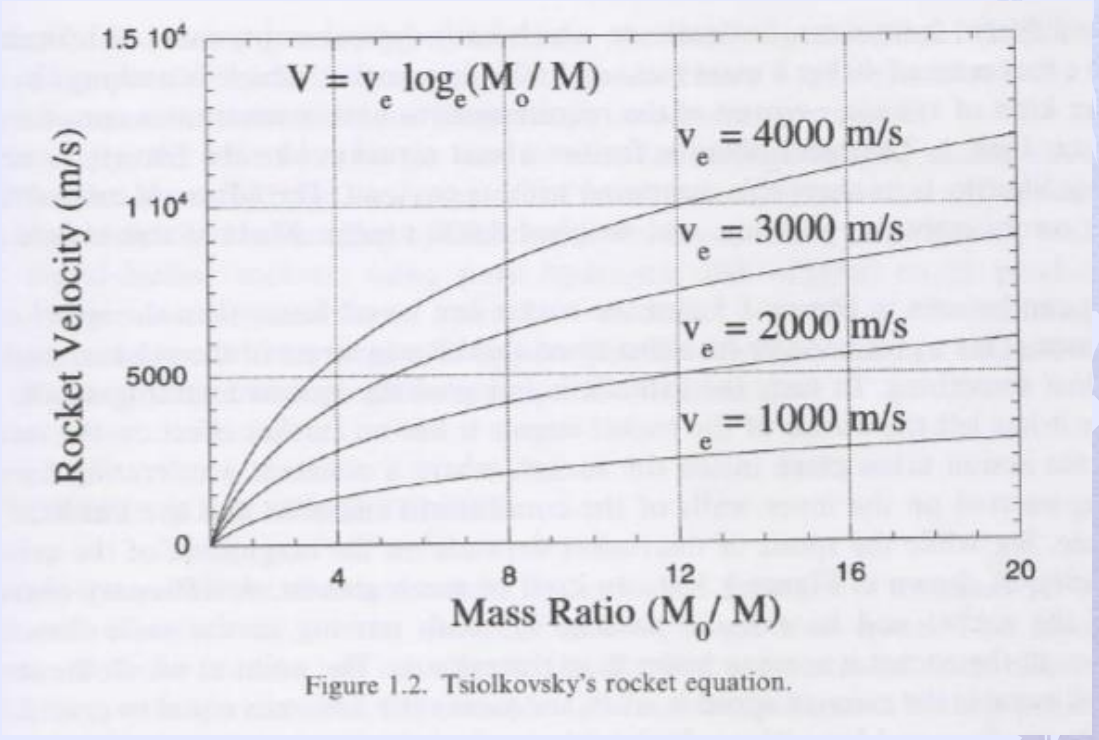
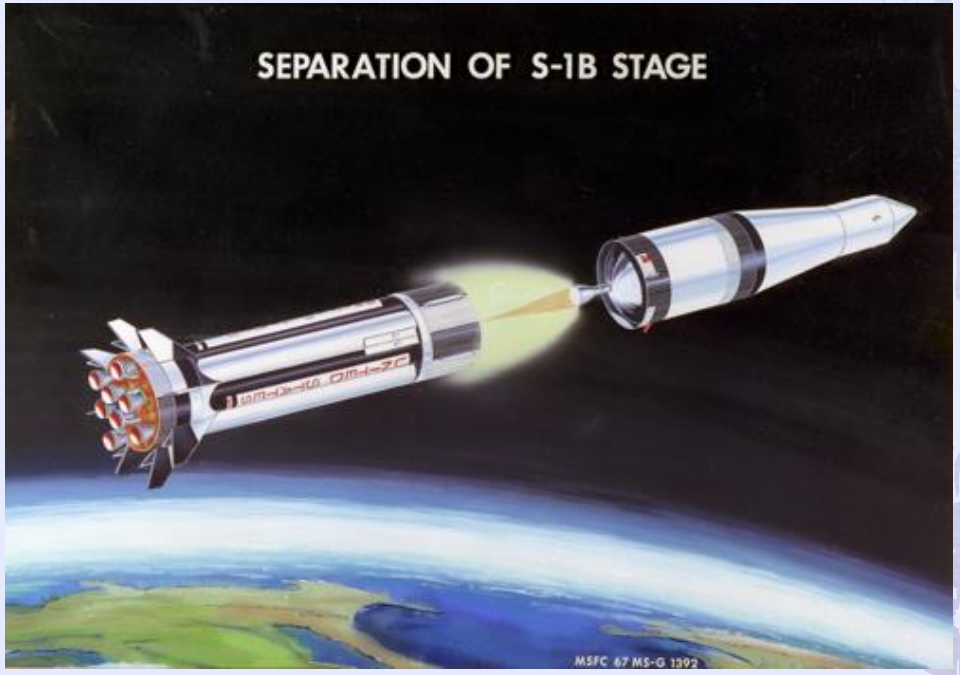


Figure 1.2. Tsiolkovsky's rocket equation.

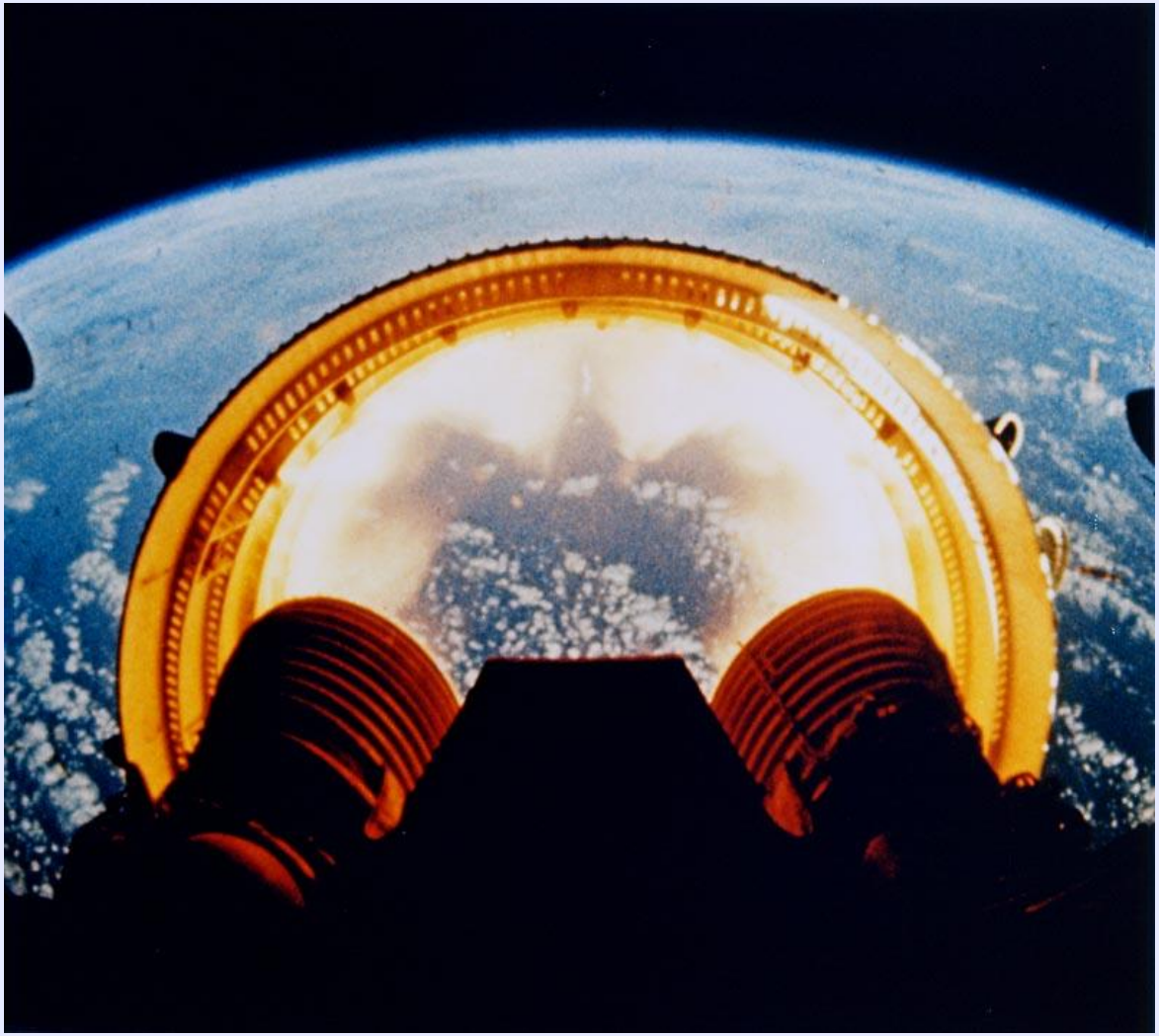
Vehicle	Takeoff Mass	Final Mass	Mass ratio	Mass fraction
Ariane 5 (vehicle + payload)	746,000 kg [124] (~1,645,000 lb)	2,700 kg + 16,000 kg[124] (~6,000 lb + ~35,300 lb)	39.9	0.975
Titan 23G first stage	117,020 kg (258,000 lb)	4,760 kg (10,500 lb)	24.6	0.959
Saturn V	3,038,500 kg[125] (~6,700,000 lb)	13,300 kg + 118,000 kg[125] (~29,320 lb + ~260,150 lb)	23.1	0.957
Space Shuttle (vehicle + payload)	2,040,000 kg (~4,500,000 lb)	104,000 kg + 28,800 kg (~230,000 lb + ~63,500 lb)	15.4	0.935
Saturn 1B (stage only)	448,648 kg[126] (989,100 lb)	41,594 kg[126] (91,700 lb)	10.7	0.907
Virgin Atlantic GlobalFlyer	10,024.39 kg (22,100 lb)	1,678.3 kg (3,700 lb)	6.0	0.83
V-2	13,000 kg (~28,660 lb) (12.8 ton)		3.85	0.74 [127]
X-15	15,420 kg (34,000 lb)	6,620 kg (14,600 lb)	2.3	0.57[128]
Concorde	~181,000 kg (400,000 lb [128])		2	0.5[128]
Boeing 747	~363,000 kg (800,000 lb[128])		2	0.5[128]

Staging

- Staging involves dropping off unnecessary parts of the rocket to reduce mass
- Often, the required velocity (delta-v) for a mission is unattainable by any single rocket
- Because the propellant, tankage, structure, guidance, valves and engines and so on, take a particular minimum percentage of take-off mass that is too great for the propellant it carries to achieve that delta-v



Apollo 6 while dropping the interstage ring



Apollo 11 camera E8

- https://www.youtube.com/watch?v=DKtVpvzUF1Y

- Discovery Launch multiple cameras
- https://www.youtube.com/watch?v=vFwqZ4qAUkE

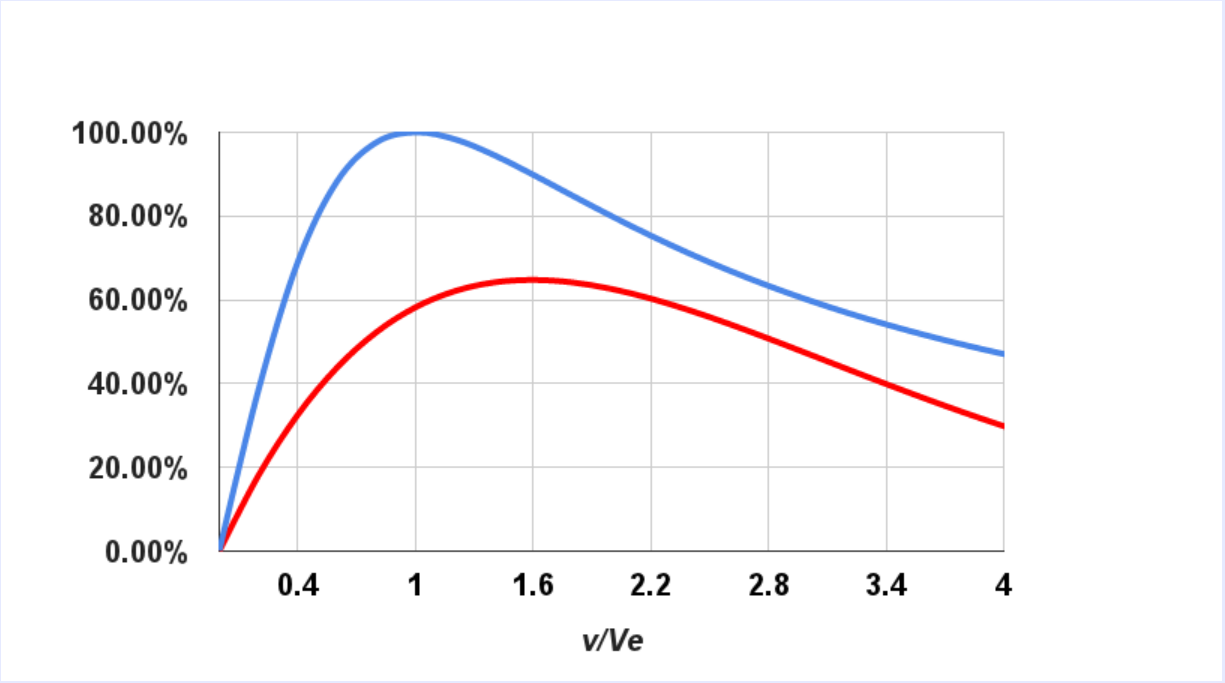
Mars Rover & Curiosity

- https://www.youtube.com/watch?v=XRCIzZHpFtY

- Curiosity
- https://www.youtube.com/watch?v=FZYnIsLNz3c

Energy Efficiency

- Plot of instantaneous propulsive efficiency (blue) and overall efficiency for a rocket accelerating from rest (red) as percentages of the engine efficiency



Sometimes things go wrong

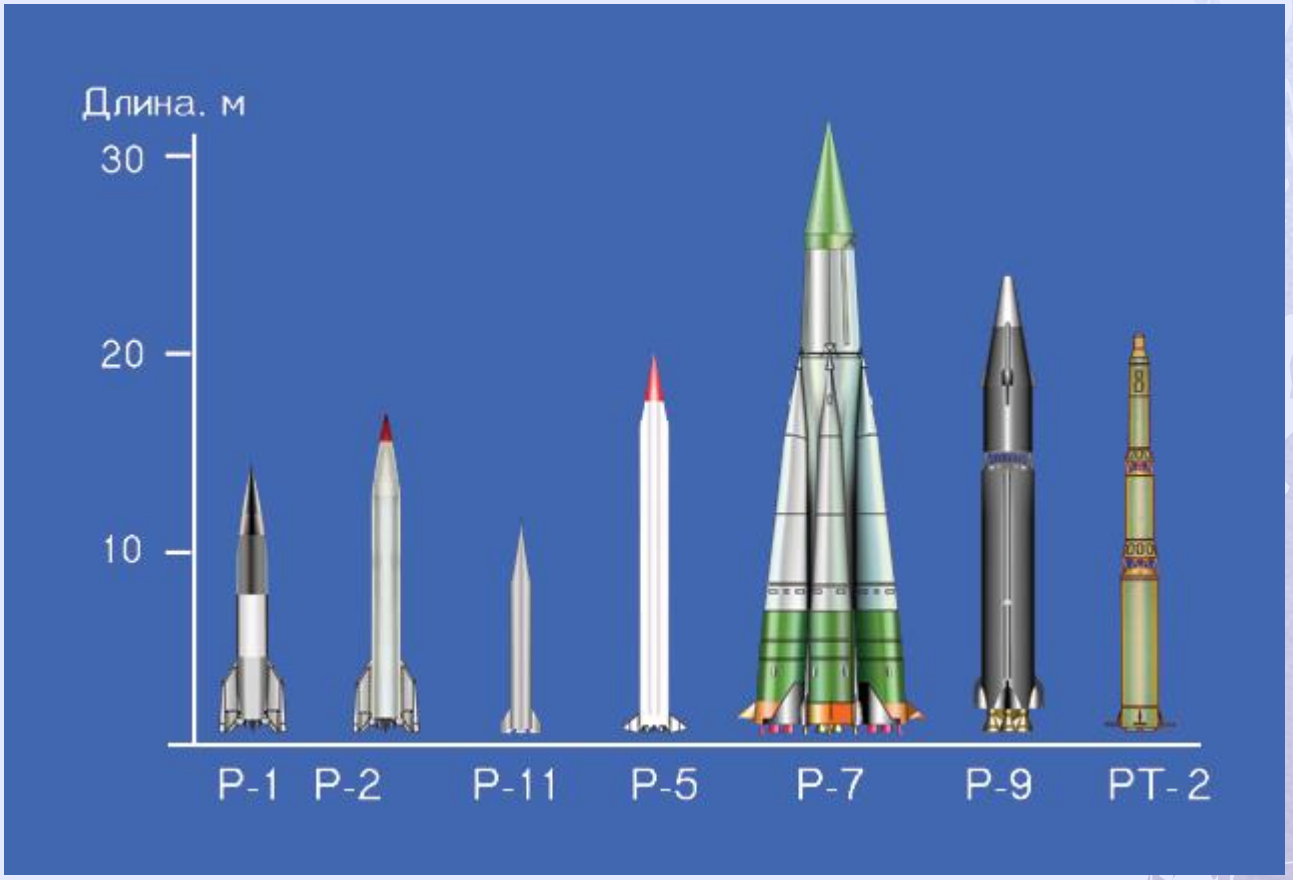
- Space Shuttle Challenger was torn apart 73 seconds after launch after hot gases escaped the SRBs, causing the breakup of the Shuttle stack

Russian Rocket Technology

- The first launch of A-4 rocket assembled on the basis of components and assemblies of German rocket V-2;
- Missiles systems with ballistic missiles P-1, P-2, P-9, PT-1, PT-2, PT-2P (PT-1, -2 are solid-propellant rockets) were developed and subsequently put into service;
- Strategic missile P5 and tactical missile P-11 were developed;
- The latter was modified for launches from submarines and was indexed as P-11FM;
- Two-stage intercontinental ballistic missiles P-7 and P-9, three-stage Vostok launch vehicle (consisting of P-7 and upper stage Block E as a third stage) for missions to the Moon, and four-stage Molniya launch vehicle for launching payloads to Venus and Mars (consisting of P-7 and upper stages Block I and Block L) were developed;

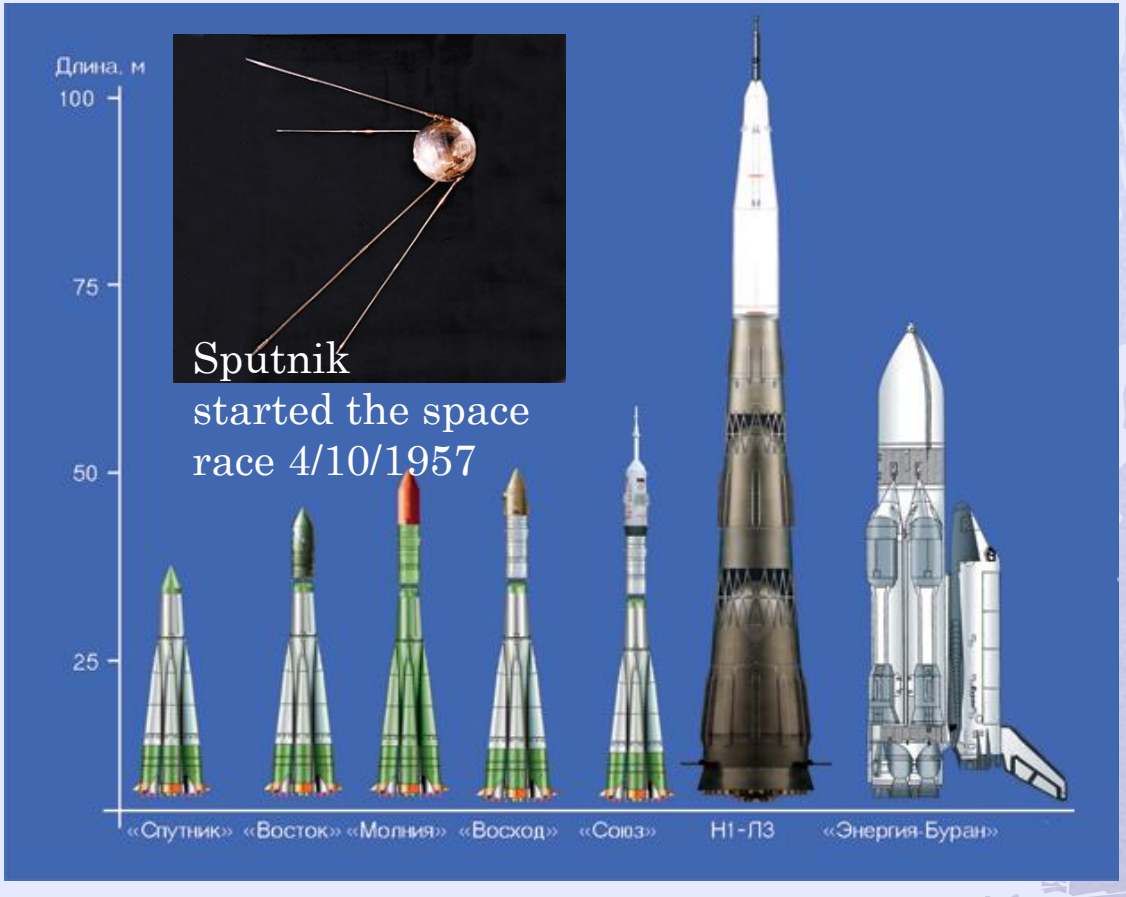
Russian Missiles

- **1950** - the first ballistic missile **P-1**
  1952 - **P-2** with detachable warhead
  1955 - **P-11** for ground forces
  1956 - **P-5M** with a nuclear charge
  1958 - **P-11M** a mobile missile
  1959 - **P-11FM** for submarines
  1960 - the first intercontinental ballistic missile **P-7**
  1960 - **P-7A**
  1965 - **P-9A**
  1968 - **PT-2** a solid-propellant rocket
  1972 - **PT-2P**



Russian Space Launch Vehicles

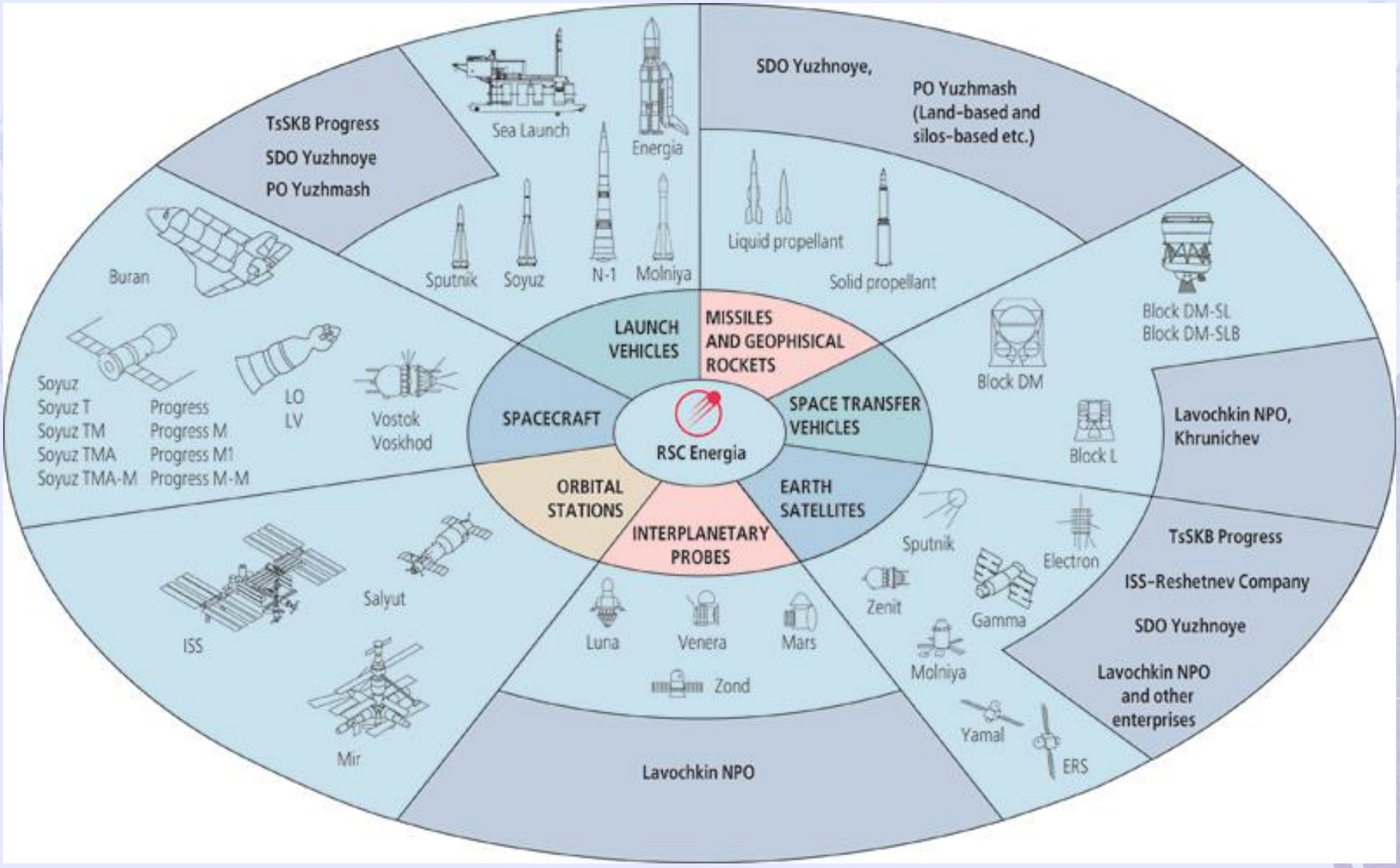
- **1957 - 1958** - Launch vehicle - **Sputnik** - Earth artificial satellites-1, -2, -3
  1958 - 1991 - **Vostok** - Luna robotic spacecraft and manned spacecraft
  since 1960 - **Molniya** - communications, exploration of the Moon, Mars, Venus
  1963 - 1976 - **Voskhod** - manned spacecraft and Zenit SC
  since 1966 - **Soyuz** - manned and logistics spacecraft, exploration of the Moon
  1969 - 1972 - **Launch vehicle system N1-L3**
  1987 - 1988 - **Reusable space transportation system Energia-Buran**
  с 1999 - **Space launcher system Sea Launch**



Liquid-Propellant Rocket Engine 11D33

- The first domestic liquid-propellant rocket engine with afterburning of generated gas in a combustion chamber allowed it to achieve a specific impulse of up to 340 kgf s/kg in vacuum when using main components
- The engine is attached to a Cardan's suspension with an angle of rotation of up to 3°

Russian Space Agency Achievements



Summary

- Invention preceded theory by 1000 years
- Theory preceded first successful vehicle (V2) by 50 years
- This is due to serious engineering problems that needed to be solved
- Rockets are unstable and need to be guided
- Rockets are high power devices that push material and components to their limits of stress and temperature

The End